

LORETA indicates frequency-specific suppressions of current sources within the cerebrums of blindfolded subjects from patterns of blue light flashes applied over the skull

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ABSTRACT

An array of eight cloistered (completely covered) 470-nm LEDs was attached to the right caudal scalp of subjects while each sat blindfolded within a darkened chamber. The LEDs were activated by a computer-generated complex (frequency-modulated) temporal pattern that, when applied as weak magnetic fields, has elicited sensed presences and changes in LORETA (low-resolution electromagnetic tomography) configurations. Serial 5-min on to 5-min off presentations of the blue light (10,000 lx) resulted in suppression of gamma activity within the right cuneus (including the extrastriate area), beta activity within the left angular and right superior temporal regions, and alpha power within the right parahippocampal region. The effect required about 5 min to emerge followed by a transient asymptote for about 15 to 20 min when diminished current source density was evident even during no light conditions. Subjective experiences, as measured by our standard exit questionnaire, reflected sensations similar to those reported when the pattern was presented as a weak magnetic field. Given previous evidence that photon flux density of this magnitude can penetrate the skull, these results suggest that properly configured LEDs that generate physiologically patterned light sequences might be employed as noninvasive methods to explore the dynamic characteristics of cerebral activity in epileptic and nonepileptic brains.

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1. Introduction

The sensitivity of the human brain as inferred by quantitative electroencephalography (QEEG) and sLORETA (low-resolution electromagnetic tomography) to external sources of *physiologically patterned* electromagnetic fields and energies has been demonstrated by several experiments [1]. “Physiologically patterned” refers to those complex temporal sequences that are similar to those generated by cerebral tissue rather than symmetrical, sinusoidal, or square-wave signatures generated by traditional electronic devices. Similarly patterned magnetic fields have been shown to affect the nociceptive thresholds for rodents [2] and planarians [3] and to influence signaling pathways within malignant cells [4]. Irregularly patterned magnetic fields can be “sensed” by cells. The importance of precise timing within the domain occupied by EEG activity has been reported [5].

Neuronal cells and hippocampal slices emit photons with radiant flux densities in the order of $10^{-12} \text{ W} \cdot \text{m}^{-2}$ whose amplitude fluctuations are coupled in real time with electrophysiological patterns [6].

Cells also respond to photons within the visible wavelengths [7]. There have been multiple recent experiments demonstrating the effectiveness of specific wavelength photon densities delivered through LEDs (light-emitting diodes) upon the cell plasma membrane [8] and the molecular pathways associated with its stimulation. The new areas of “optogenetics” [9] by which cell function is controlled by light and “photoimmunotherapy” whereby near-infrared wavelengths are employed to target specific molecules indicate that photon stimulation may have potential application to electrophysiological phenomena such as those involved with epilepsy. Intercellular photon emissions may be a central method of interaction and exchange of information between cells. Biophotons can also be detected approximately 15 cm from the side of the right (but not the left) hemisphere when people sit in hyper-dark settings and engage in imagination of white light. The fluctuations in the photon flux density were correlated 0.9 with the power of beta EEG activity over the left prefrontal region [10].

Elicitation by visually discernible light pulses of paroxysmal EEG activity from the brains of patients who have been diagnosed with epilepsy has been a classic method of clinical verification of the vulnerability of some cerebral tissue to recruitment and summation in response to repetitive stimuli [11]. However, the effects of photons applied to the human skull *without* being processed directly by the retinal visual

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system have not been systematically explored. Persinger et al. [12] demonstrated that application of 10 klx different fixed-frequency light flashes applied against the skull resulted in small, reliable increases ($\sim 2.5 \cdot 10^{-11} \text{ W} \cdot \text{m}^{-2}$) in photon emissions from the opposite side of the head as measured by photomultiplier tubes (PMTs) or digital units. The effect was most reliable with either constant light or light flashed between 3 Hz and 7 Hz. When the light stimulation occurred, there was enhanced QEEG (quantitative electroencephalographic) power within the theta and the low beta range. The power within the right parahippocampal region was particularly enhanced.

In that study, subjects were blindfolded while sitting in a darkened chamber. Any extraneous light from the light source was blocked with several layers of black towels. That the response latency was about 1 s and that the difference between applications of the light along the X-axis (left versus right) compared with the Z-axis (rostral–caudal) reflected the actual distance ratio of the cerebrum indicated that the effect was not artifact. If there had been “inadvertent light”, the PMT response would have been conspicuous, immediate, and protracted. The study had been inspired by the results of Starck et al. [13] who showed that light applied with a flux density of 8000 lx to the ear canals from LEDs with a primary peak spectrum at 465 nm or blue color (and a secondary peak at 550 nm) elicited clear and specific changes in fMRI (functional magnetic resonance imaging) profiles. The greater functional connectivity during the external light stimulation was significantly greater (equivalent to about 5.2 cm^3) across the extrastriate visual cortices. A smaller locus of enhancement occurred in the region of the locus ceruleus and anterior cerebellum. The functional connectivity during the light stimulation gradually increased during the first 5 min and displayed an asymptote after about 6 min.

Considering the specific changes within cerebral space as measured by sLORETA when a weak, frequency-modulated, spatially rotating magnetic field was applied with slightly greater intensity over the right temporal lobe, we designed an experiment whereby light from blue (470 nm) LEDs with base intensities of about 10,000 lx would be applied instead on the skull over the caudal right temporal lobe region. Brief (15 to 30 min) applications of physiologically patterned magnetic fields have been associated with the experience of altered states and sensed presences similar to those reported by patients who have been diagnosed with complex partial epileptic seizures and when such patients received direct electrical stimulation within the temporal lobes [14]. Here, we report that this complex temporal pattern when applied over the caudal right temporal lobe as temporal configurations of blue light (similar to that employed by Starck et al. [13]) within a relatively narrow wavelength elicited clear changes in specific brain activities within the cerebrum as measured by sLORETA. The change was sufficient to be potentially useful for revealing recondite conditions that are consistent with complex partial epilepsy or for related forms of electrical lability.

2. Methods

A total of 7 (4 males and 3 females) participants volunteered for the experiment after the protocol had been approved by the University's Research Ethics Board. Each participant sat within a comfortable arm chair that was housed within an acoustic chamber (13 m^3). A sensor cap (Electro-Cap International) with 19 AgCl sensors, sited according to the 10–20 International Standard of Electrode placements, was placed onto the scalp for monopolar (reference to the ear) recordings. Impedance of all sensors was maintained less than 10 k Ω . Data collection to the laptop computers external to the closed chamber was by a Mitsar 201 system amplifier, using a sampling rate of 250 Hz with an input range of $\pm 500 \mu\text{V}$ and a 16-bit analog-to-digital conversion [15]. The subject was then blindfolded with triple layer material to ensure that no light was experienced during the experiment.

A custom-constructed LED application device was then placed and maintained by Velcro just behind the right ear at the level of the

temporal lobe. The entire device was further secured with an additional Velcro band. The device was composed of 8 (4 pairs) 470-nm LEDs (Fig. 1). The onset of light emissions for each of the pairs of LEDs was controlled by the frequency-modulated (“Thomas”) pattern by a laptop computer. Its temporal configuration has been published several times [3,16]. It is composed of 839 points with values between 0 and 256 which are transformed to voltages between -5 and $+5$. The point duration, or the time the current activated each pair of LEDs, was 3 ms in order to simulate the optimal point duration that has shown to be effective when this pattern is presented as approximately 1 to 5 μT magnetic fields [17]. However, the magnetic field intensity produced by the LED device was only 50 to 90 nT (0.5 to 0.9 mG) or comparable with the background 60-Hz power levels.

Thirty-second segments extracted from the end of each ~ 5 -minute trial (light off/light on), for each of 3 participants (with the most artifact free records), were segmented into 5-second segments. Each of these segments (total = 108) was then imported into sLORETA software for computation of current source densities. Simple paired t-tests were performed using the statistics function in the sLORETA package to compare light-off and light-on segments. For further statistical analyses, current source densities ($\mu\text{A} \cdot \text{mm}^{-2}$) for ROIs of the major effects were computed using the sLORETA to ROI function. These data were then imported into SPSS. Although the analyses of the other 4 subjects' records were similar for different blocks (on–off pairs), at least one block was ambiguous because of electronic artifacts from the LED array that began immediately upon activation and stopped with termination.

After the exposure, each subject was given the experience rating questionnaire whose items were listed by Persinger and Saroka [14]. One set of items ($n = 20$) involves ratings of various experiences (0 = never, 1 = at least once, 2 = frequently) that included sensations (for example) of dizziness, sensed presence, visual images, various measures of emotion (including terror), odd tastes, childhood memories, and images from dreams. This form was administered in order to compare, semiquantitatively, the profile of experiences associated with the LED stimulation with that reported following exposures to physiologically patterned magnetic fields. The means of the scores for each of the items were converted to z-scores and compared with the profile of within item z-scores reported in Table 1 [14] for surgical stimulation from published clinical cases and from university and film crew populations exposed to the weak externally applied magnetic fields. Correlations of these scores for the 20 items between the three groups and the group from the present study were completed. Residuals following regression analyses between the university group exposed to weak magnetic fields across the temporal lobes and the present LED-exposed group were completed to discern any potential differences in the subjective profiles with respect to the clinical literature. The point of this analysis was to discern the differences in the pattern of the experiences rather than the significant differences in the magnitudes of a particularly reported experience.

3. Results

The most conspicuous effect revealed by the sLORETA paired t-tests indicated a significant suppression ($t = -6.13$, $p < .05$) of gamma (>30 Hz) activation within the cuneus of the left and right occipital regions (Fig. 2A). When the saved ROI seeds were graphed as a function of condition (light off/light on), there was a conspicuous decrease in current source density of the right cuneal region for the first two trials, with an increase during the third trial (Fig. 2B). The graph revealed that, except for one trial in the first participant, there was always a suppression of gamma activity upon light stimulation relative to the eye-closed baseline (no light) collected before the beginning of the experiment.

The initial sLORETA statistical analysis also revealed a significant ($t = -4.08$, $p < .05$) suppression of power within beta-3 (25–30 Hz) range over the left angular and right middle temporal gyri (Fig. 2A).

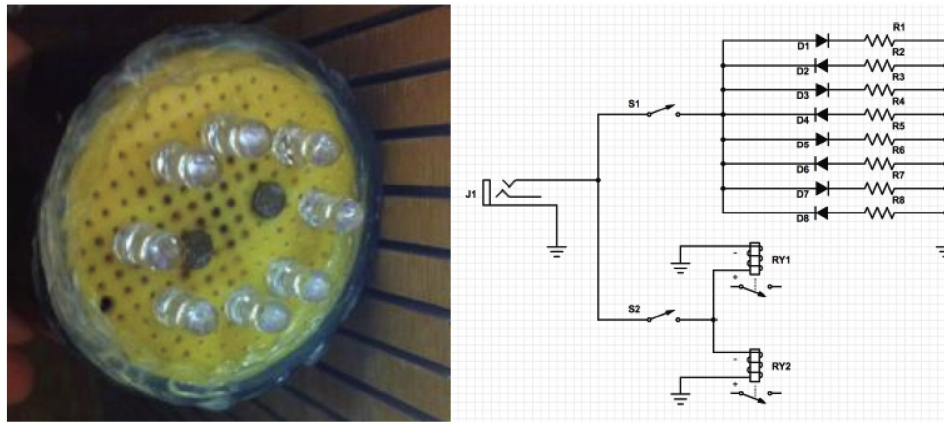


Fig. 1. Pictures of the LED arrangement (and schematic) that was placed over the caudal right head of the participant.

One-way analyses of variance for the current source densities for these regions confirmed that the effects were significant for the left ($F = 12.39$, $p < .05$, ω^2 estimate = .10) and right ($F = 10.18$, $p < .05$, ω^2 estimate = .09) regions. Finally, analyses indicated that portions of the right lingual and parahippocampal gyri showed a significant ($t = -4.10$, $p < .05$) suppression of high-alpha (10–13 Hz) activity (Fig. 4).

The results of the questionnaire analyses when compared with the standardized averaged scores for surgical stimulation groups and either students or film crews exposed to the weak transcerebral magnetic fields across the temporal lobes indicated that only the scores for the latter two groups were correlated ($r = 0.98$) significantly. The scores for the LED-stimulated group in this experiment were not significantly correlated ($r_s: \sim 0.30$) with the university and film groups or with the surgically stimulated population ($r = 0.15$). Rank order (Spearman) correlations revealed similar results. Regression analyses between the

scores for the university students that had received the magnetic field stimulation and the present group that received the LED over the right caudal temporal lobes indicated residuals that were significantly ($p < .05$) higher for the frequency of sensed presences, visual images, anger, and recurrent ideas for the latter group. The residuals for the LED-exposed group indicated significantly fewer reports of pleasant vibrations moving through the body, sadness, and thoughts from childhood.

4. Discussion

Bright light that stimulates the retinal–geniculate–occipital pathways within the brain is well known to affect mood for patients diagnosed with certain seasonal disorders [18]. When pulsed within the range of the major electroencephalographic power frequency (around 10 Hz), bright light can elicit either electrical seizures or overt epileptic

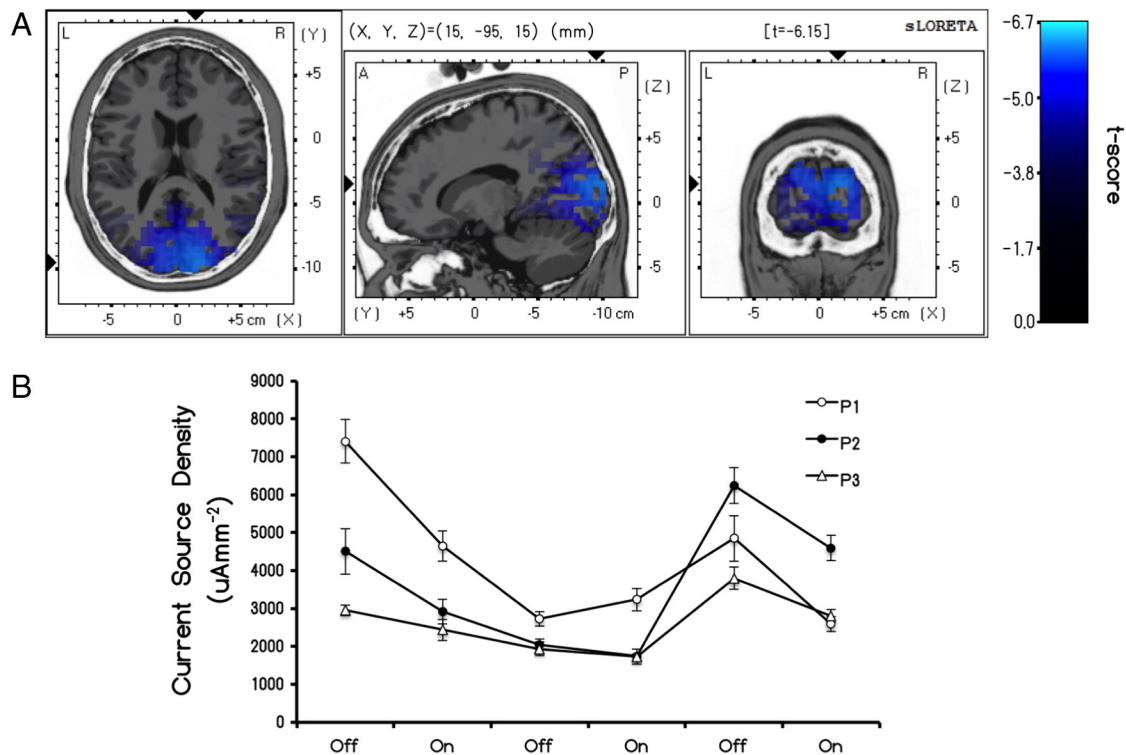


Fig. 2. A) LORETA indicators (in blue) where the gamma activity was diminished during the application of temporally configured LED rotations external to the right side of the skull. B) Current source density as a function of the light configuration successive presentation (5 min) and absence (5 min) during the 30-minute experiment. P refers to the different participants. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

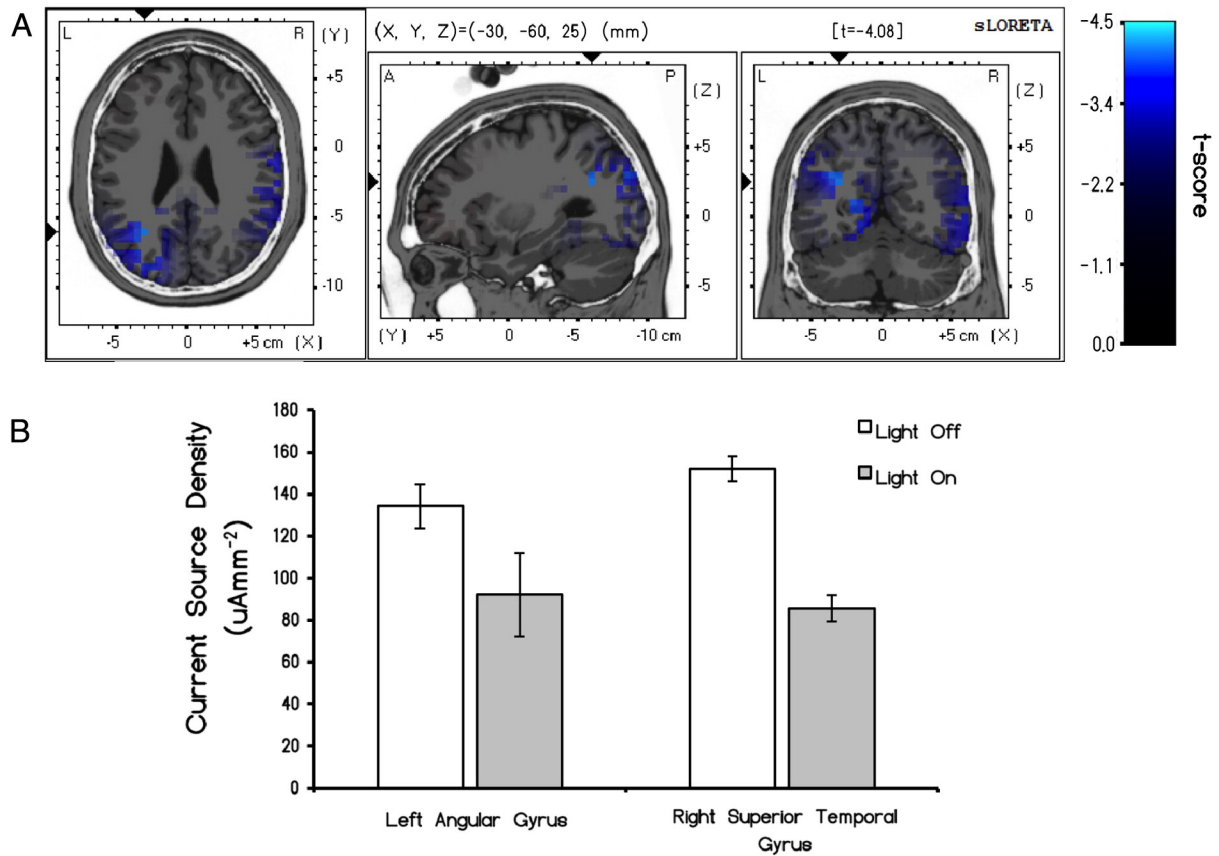


Fig. 3. A) Regions of the cerebrum according to LORETA where the beta activity was diminished during external LED stimulation over the right side of the head compared with no light conditions. B) Averaged current source density within the left angular gyrus and right superior temporal gyrus during light-on and light-off conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

behaviors [11]. In this experiment, we found that application of physiologically patterned bright blue light of approximately 10 klx over the right caudal skull when the retinal input is not activated can elicit localized shifts in specific bands of electrical activity within the cerebral volume. The results are similar to those reported by Starck et al. [13] who found that similar light intensities delivered through a tube into the ear canal enhanced the configuration of activity within the extrastriate cortices as measured by fMRI.

We employed blue (470 nm) light in this study because of our success with influencing proliferation in incubating cell cultures. Exposure of people to about 33 lx of 470-nm wavelengths through retinal pathways suppresses nocturnal melatonin [19]. Protracted exposure of white collar employees during work hours to blue-enriched white light around 400 lx has been reported to increase self-reported alertness and sleep quality [20]. Functional magnetic resonance imaging measurements from individuals performing working memory tasks while being exposed to about 29 lx of 473 nm light showed increased “activity” in the left hippocampus and thalamus and right amygdala and insula [21]. Vandewalle et al. [21] reported that 18 min of exposure was required to produce the effect, suggesting a substantial latency for the nonvisual responses to “build-up” in the cortex. The functional connectivity within the extrastriate cortices as measured by fMRI during direct application of more intense blue light through the ear canal required about 6 min to achieve asymptote [13].

Our results are not likely to be artifacts of retinally mediated light effects. If they were artifacts, the changes would have been increased activity (power) of higher frequencies within wide regions of the caudal cerebrum that would have begun immediately. Instead, the changes were primarily suppression of power, as inferred by the LORETA current density measurements, within primarily higher frequencies. The diminished gamma power within regions that could be considered

extrastriate was similar to that measured by fMRI by Starck et al. [13]. We found statistically significant more suppression of indicators of current source within the right cuneus, the same side over which the light was applied, which was not as evident in the left cuneus. Both results suggest that the region of the cerebrum that is activated by the action potentials generated by the pathways that begin within the retina might also be activated by direct stimulation by photons “induced” within these regions.

If this assumption was even partially valid, then Bokkon's innovative hypothesis [22] that visual imagery is a field of photons and not simply the experiential correlate of the pattern or tensor field of action potentials from the retina, per se, might be supported. There is experimental evidence that retinal cells emit photons [23]. Our research [24] has shown that a variety of malignant and nonmalignant cells in culture emit photon densities equivalent to about 10^{-20} J per second per cell or in the order of 10^{-12} W·m⁻². The latter is within the radiant flux density measured from hippocampal slices coupled with theta frequency amplitudes [6]. Recently [25], we found that morphine injected into melanoma cells in culture resulted in an increase of photon emissions by a factor of ten. Such enhancement would be sufficient to potentially affect hundreds of thousands of cells within the adjacent populations.

We also measured a reliable diminishment of beta activity within the right superior temporal lobe and left angular gyrus (Fig. 3). A functional reciprocal relationship between the superior temporal lobe and the inferior parietal region in the same hemisphere has been established. For example, Karnath et al. [26] showed that the classic symptom of contralateral neglect following right inferior parietal lobe damage was also associated with marked increase in activity in the right superior temporal lobe. In other words, spatial awareness is a function of the temporal lobe. One explanation for the interhemispheric “coherence” of the suppression of 25- to 30-Hz activity is that these

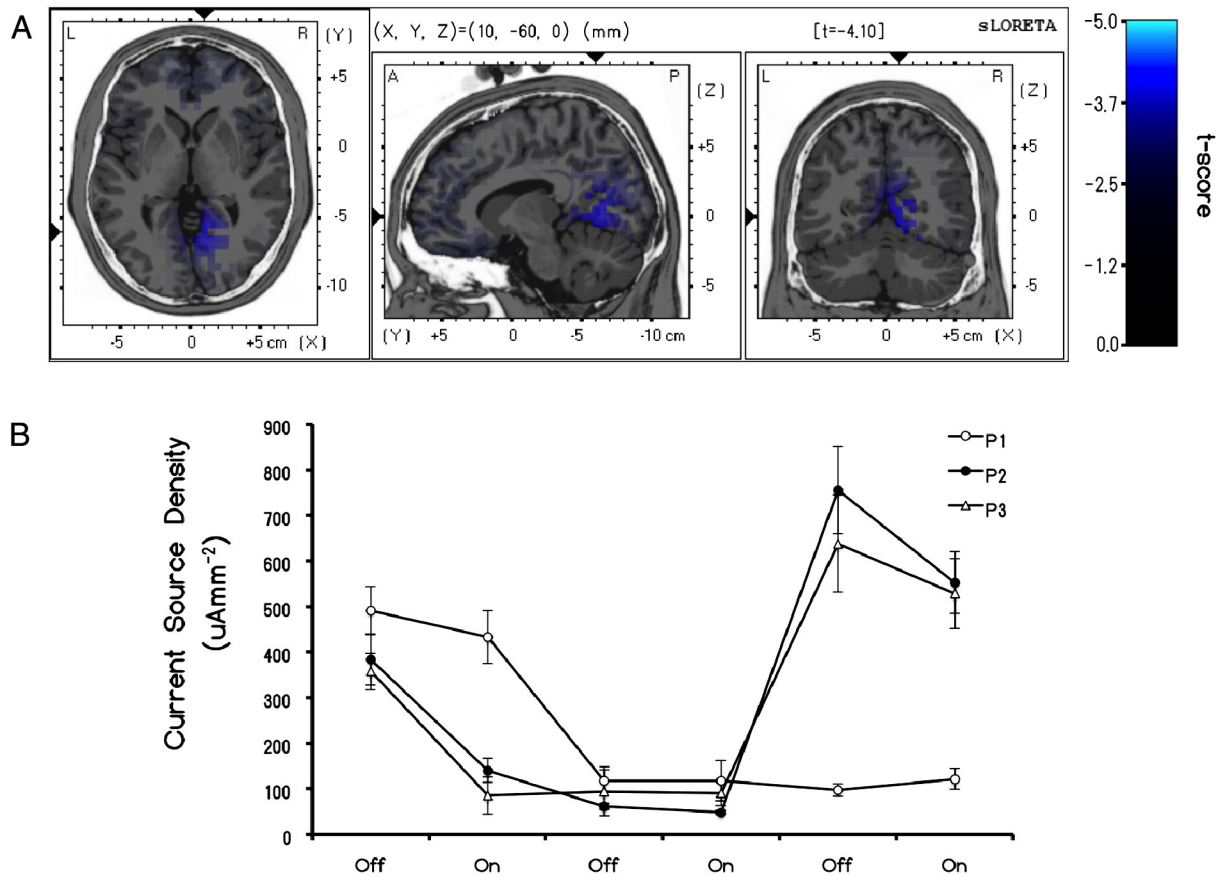


Fig. 4. A) Right parahippocampal and adjacent regions of suppression of alpha power during light presentation compared with no light presentation for three participants. B) Current source density as a function of durations when the external application of the temporal configuration of light flashes was not applied or applied to the skull. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

two regions are related by a similar band of electrophysiological activity that is stimulated by photons pulsed at 3-ms intervals as a complex, frequency-modulated pattern. According to Gloor [27], the caudal superior gyrus of the temporal lobe, particularly within the sulcus, was an area from which subjective experiences were generated more frequently by direct electrical stimulation in patients diagnosed with complex partial epilepsies.

From a theoretical and clinical perspective, the diminished power within the alpha range within the right hemisphere only at the level of the right parahippocampal and lingual region was particularly intriguing. This was the same side over which the LED pattern had been applied upon the skull. If the diminished power within this frequency band was associated with a generally greater activity across the faster bands, then the conditions for parahippocampal asymmetry could have occurred. When this occurs metabolically and if the patient is prone, panic attacks can be reported [28]. In the present study, some subjects reported frank panic or terror during the period of light stimulation. In our previous experiments [12], when static or redundantly applied frequencies of white light flashes at comparable intensities were applied across the back of the skull, the right parahippocampal region was also most responsive as defined by LORETA source localization.

From the perspective of mechanism or process, one important question is how many photons penetrated into the brain tissue? Persinger et al. [12] found that application of 10-klx steady white light over the caudal skull resulted in an increase of about $2.5 \cdot 10^{-11} \text{ W} \cdot \text{m}^{-2}$ from the frontal skull (at 15 cm) which required about 1 s to occur. Calculations indicated that this would be time for discrete amounts of photon energy to be transmitted along a Grotthuss chain of protons within the hydronium ions of water at the typical extracellular pH found in cerebral tissue. Many researchers often forget that the scalp

is composed of muscles which are living cells and that the skull is composed of bone whose osteocytes not only are living but also occupy myriad lacunae and canaliculi that are connected by Haversian and Volkmann's channels. We have shown that application of the same photon source to a comparable thickness of a plank of dried pine (wood) resulted in no change in photon emissions from the opposite side with this light intensity.

One of the methods by which to test the validity of an assumption concerning the physical dynamics of brain structure and function is to discern the degree of congruence between quantitative solutions. The net change (decrease) of current source density following the light stimulation in this study within the left angular gyrus and right superior temporal gyrus was about $60 \mu\text{A} \cdot \text{mm}^{-2}$. If we assume that the application of the blue 10-klx pattern over the right caudal skull resulted in changes of $2.5 \cdot 10^{-12} \text{ W} \cdot \text{m}^{-2}$, then the power within 1 mm^2 or 10^{-6} m^2 would be $2.5 \cdot 10^{-18} \text{ J} \cdot \text{s}^{-1}$. The energy (Joules) divided by unit charge ($1.6 \cdot 10^{-19} \text{ A} \cdot \text{s}$) would be $\sim 1.6 \cdot 10^{-1} \text{ V} \cdot \text{s}^{-1}$. When multiplied by the sampling frequency of 250 Hz ($4 \cdot 10^{-3} \text{ s}$), the functional voltage would be $\sim 60 \text{ mV}$. This is a realistic average value for what might be expected proximal to the plasma membrane of cells within cerebral tissue.

Similarly, if the typical intracellular concentration of potassium, $\sim 155 \mu\text{M}$ per cubic centimeter, is assumed and if the smaller areas (5 cm^3) of influence estimated in the present study reported by Starck et al. [13] were considered, the numbers of charges would be $3.6 \cdot 10^{20}$. In a cubic millimeter, this value would be $3.6 \cdot 10^{17}$ molecules. In a cross-sectional area that is the thickness of a cell soma ($10 \mu\text{m}$ or 10^{-2} mm), the number of molecules would be $3.6 \cdot 10^{15}$. Assuming the function charge for each ion of $1.6 \cdot 10^{-19} \text{ A} \cdot \text{s}$, the current would be $5.7 \cdot 10^{-4} \text{ A} \cdot \text{s}$. Fluctuating within the range measured

here (10 Hz to 40 Hz or s^{-1}), the current would most likely be within the milliamp range. This too is a realistic magnitude.

The diminishment of higher frequency activity within discrete cerebral regions that we have attributed to the application of the 10-klx blue light over the caudal right skull is a vectorial consequence that may alter our understanding of the role of photons within cerebral tissue. Several authors [29,30] have indicated that photons emitted from cells may be the information by which cells interact. The diminishment of current source, which would presumably reflect less activity of neurons during the light stimulation, may suggest that the intrinsic photons that emerged within the brain volume from the external applications of photons were substitutable for the action potentials or behaved as “virtual action potentials”. Alternatively, and more importantly from a physics perspective, the inverse relationship might suggest that the current associated with action potentials and with intracerebral photons shares a common source of variance that must maintain a specific value. It would be premature but still exciting to postulate that this commonality is “the collapse of the wave function” predicted by several theorists [31] who are pursuing the quantum biological explanations for consciousness. We [32] have suggested that etiology is shared by both the proton within hydronium ion that contributes to intracerebral pH and the photon.

The subjective experiences as inferred by the exit questionnaire suggest that the profile of “phenomenological” patterns was not significantly correlated with that reported by university students or film crews that had been exposed to physiologically patterned magnetic fields applied across the temporal lobes or with the patterns inferred from the review of patients' reports during surgical stimulation of this area. The relative increase in visual images and sensed presence reports in the LED-stimulated group but diminished reports of pleasant vibrations and sadness would be consistent with but not proof the two classes of stimuli affected different regions or processes with the brains of the participants.

The application to clinical epilepsy research could be significant. The induction of specific changes in frequency bands of activity within very specific regions of the brain volume could be a novel method for exploring the labile regions associated with complex partial epilepsies in particular. In the past, surgical stimulation was required to discern the likely foci of epileptic activity. This was invasive and labor-intensive and required extraordinary expertise by a clinical team. If differential responses to applied light stimuli delivered adjacent to the scalp as physiological patterns that could be programmable by computer and based upon either the patient's electroencephalographic profile or a theoretical model can be evoked, then this technology might be a more efficient method of discernment.

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Conflict of interest

The authors proclaim no conflict of interest with any agencies.

References

- [1] Saroka SA, Persinger MA. Potential production of Hughlings Jackson's “parasitic consciousness” by physiologically-patterned weak transcerebral magnetic fields: QEEG and source localization. *Epilepsy Behav* 2013;28:395–407.
- [2] Martin LJ, Koren SA, Persinger MA. Thermal analgesic effects from weak, complex magnetic fields and pharmacological interactions. *Pharmacol Biochem Behav* 2004;78:217–27.
- [3] Murugan NJ, Persinger MA. Comparisons of responses by planarian to micromolar to attomolar dosages of morphine or naloxone and/or weak pulsed magnetic fields: revealing receptor subtype affinities and non-specific effects. *Int J Radiat Biol* 2014;90:833–40.
- [4] Karbowski LM, Harribance SL, Buckner CA, Mulligan BP, Koren SA, Lafrenie RM, et al. Digitized quantitative electroencephalographic patterns applied as magnetic fields inhibit melanoma cell proliferation in culture. *Neurosci Lett* 2012;523:131–4.
- [5] Litovitz TA, Penafiel M, Kraus D, Zhang D, Mullins JM. The role of temporal sensing in electromagnetic effects. *Bioelectromagnetics* 1997;18:388–96.
- [6] Isojima Y, Isoshima T, Nagai K, Kikuchi K, Nakagawa H. Ultraweak bioluminescence detected from rat hippocampal slices. *Neuroreport* 1995;6:658–60.
- [7] Nissila J, Manttari S, Sarkioja T, Tuominen H, Takata T, Timonen M, et al. Enkephalopsin (OPN3) protein abundance in mouse brain. *J Comp Physiol A* 2012;198(11):833–9.
- [8] Wu H-PP, Persinger MA. Increased mobility and stem-cell proliferation rate in *Dugesia tigrina* induced by 880 nm light emitting diode. *J Photochem Photobiol B* 2011;102:156–60.
- [9] Deisseroth K. Optogenetics. *Nat Methods* 2011;8:26–9.
- [10] Dotta BT, Saroka KS, Persinger MA. Increased photon emission from the head while imaging light in the dark is correlated with changes in electroencephalographic power: support for Bokkon's biophoton hypothesis. *Neurosci Lett* 2012;513:151–4.
- [11] Niedermeyer E, Lopes da Silva F. *Electroencephalography: basic principles, clinical applications and related fields*. Munich: Urban and Schwarzenberg; 1987.
- [12] Persinger MA, Dotta BT, Saroka KS. Bright light transmits through the brain: measurement of photon emissions and frequency-dependent modulation of spectral electroencephalographic power. *World J Neurosci* 2013;3:10–6.
- [13] Starck T, Nissila J, Aunio A, Abou-Elseoud A, Remmes J, Nikkinen J, et al. Stimulating brain tissue with bright light alters functional connectivity in brain at resting state. *World J Neurosci* 2012;2:81–90.
- [14] Persinger MA, Saroka KS. Comparable proportions of classes of experiences and intracerebral consequences for surgical stimulation and external application of weak magnetic field patterns: implications for converging effects in complex partial seizures. *Epilepsy Behav* 2013;27:220–4.
- [15] Saroka KS, Persinger MA. Quantitative evidence for direct effects between earth-ionosphere Schumann resonances and human cerebral activity. *Int Lett Chem Phys Astron* 2014;20(2):166–94.
- [16] Dotta BT, Persinger MA. “Doubling” of local photon emissions when two simultaneous, spatially-separated, chemiluminescent reactions share the same magnetic field configurations. *J Biophys Chem* 2012;3:72–80.
- [17] St-Pierre LS, Persinger MA. Experimental facilitation of the sensed presence is predicted by specific patterns of applied magnetic fields not by suggestibility: re-analyses of 19 experiments. *Int J Neurosci* 2006;116:1–18.
- [18] Rosenthal NE, Sack DA, Wehr TA. Light, seasonal effects of mood. role of: melatonin. In: Adelman G, editor. *Encyclopedia of neuroscience*, vol. 1. Boston: Berkhauser; 1987. p. 586–8.
- [19] Figueiro MG, Wood B, Plitnick B, Rea MS. The impact of light from computer monitors on the melatonin levels in college students. *Biog Amines* 2011;25:106–16.
- [20] Viola AU, James LM, Schlangen IJM, Dijk D-J. Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scand J Work Environ Health* 2008;34:297–306.
- [21] Vandewalle G, Schmidt C, Albouy G, Sterpenich V, Darsaud A, Rauchs G, et al. Brain response to violet, blue and green monochromatic light exposures in humans: prominent role of blue light and the brain stem. *PLoS One* 2007(11):e1247.
- [22] Bokkon I. Dreams and neuroholography: an interdisciplinary interpretation of development of homeotherm state in evolution. *Sleep Hypn* 2005;7:61–76.
- [23] Wang C, Bokkon I, Dai J, Antal I. First experimental demonstration of spontaneous and visible light-induced photon emission from rats eyes with particular emphases on their roles in discrete dark noise and retinal phosphores. *Brain Res* 2011;1369:1–9.
- [24] Dotta MA, Buckner CA, Cameron D, Lafrenie RF, Persinger MA. Biophoton emission from cell cultures: biochemical evidence for the plasma membrane as the primary source. *Gen Physiol Biophys* 2011;30:301–9.
- [25] Murugan NJ, Dotta BT, Karbowski LM, Persinger MA. Conspicuous bursts of photon emissions in malignant cells cultures following injections of morphine: implications for cancer treatment. *Int J Curr Res* 2014;6:10588–92.
- [26] Karnath HO, Ferber S, Himmelbach M. Spatial awareness is a function of the temporal but not the posterior lobe. *Nature* 2001;411:950–3.
- [27] Gloor P. *The temporal lobe and the limbic system*. N.Y.: Oxford University Press; 1997.
- [28] Massana G, Serra-Grabulosa JM, Salgado-Pineda P, Gasto C, Junque C, Massana J, et al. Parahippocampal gray matter density in panic disorder: a voxel-based morphometric study. *Am J Psychiatry* 2003;160:566–8.
- [29] Fels D. Cellular communication through light. *PLoS One* 2009;4(4):e5086.
- [30] Trushin MV. Light-mediated “conversation” among microorganisms. *Microbiol Res* 2004;159:1–10.
- [31] Hameroff S, Penrose T. Consciousness in the universe. *Phys Life Rev* 2014;11:39–78.
- [32] Murugan NJ, Karbowski LM, Persinger MA. Serial pH increments (20 to 40 milliseconds) in water during exposures to weak, physiologically patterned magnetic fields: implications for consciousness. *Water* 2014;6:45–60.